

## An Algorithm for Removing Fauna Corrupted Data Pairs During BASS Data Reductions

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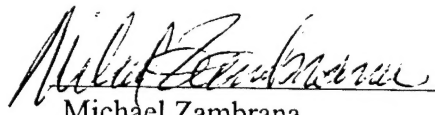
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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

  
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Michael Zambrana  
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## 1. Introduction

The Broadband Array Spectrograph System (BASS) is an infrared array prism spectrograph that covers the entire 2.9–13.5  $\mu\text{m}$  spectral region simultaneously at a resolving power of 25–120, depending on wavelength.\* The instrument is liquid-helium-cooled and uses two 58-element Blocked Impurity Band (BIB) linear arrays. End-to-end system performance (chopped) is NEP of  $2 \times 10^{-14} \text{ W Hz}^{-1/2}$  at 10  $\mu\text{m}$  and around  $3 \times 10^{-14} \text{ W Hz}^{-1/2}$  at 4.8  $\mu\text{m}$ . The circular entrance aperture is 2 mm in diameter. BASS can be configured for either f/15 or f/30 use depending on the application. The BASS instrument is often used at the Mount Lemmon Observing Facility (MLOF) in Arizona and the NASA Infrared Telescope Facility (IRTF) in Hawaii.

During observations at the MLOF and IRTF, it is not uncommon to encounter observing situations where something passes through the path between the telescope and the target object. While the angular extent of this path (referred to as the "beam") is small, it is not uncommon to have aircraft, birds, or insects cross through. Encounters with aircraft are generally few, but during temperate months the numbers of insects, birds, and bats can be significant enough to reduce the quality of a night's data.

The identity and spectral signature of the intruding objects are unknown, as is their total angular obscuration of the beam. Some encounters show such significant deviations that they can be seen in the channels monitored in real time by the observers, but smaller encounters may not be noticed. During post-processing the data containing the significant deviations can be excluded, but the smaller encounters would be missed. The data could be examined by hand for contaminated scans, but this is a tedious process at best and invites criticisms of "cherry-picking" the data. The procedure developed below represents a mathematical method of automating the exclusion of contaminated scans.

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\* Hackwell, J. A., D. W. Warren, M. Chatelain, Y. Dotan, P. Li, D. K. Lynch, D. Mabry, R. W. Russell, and R. Young, "A Low Resolution Array Spectrograph for the 2.9–13.5  $\mu\text{m}$  Spectral Region," Proc. SPIE Conference 1235 on Instrumentation in Astronomy VII (1235), 171–180 (1990).

## 2. Procedure

BASS data are taken as  $\pm$  pairs in order to subtract out the sky background that is omnipresent in the infrared wavelength regime. One or both members of a pair can be contaminated by a foreign signal, so the pair has to be excluded from further analysis. A number of pairs are stored for a given data collection, and the data from these pairs are averaged together to obtain the final signal, referred to as a "sum file." The mean and standard deviations calculated for each wavelength from each group of pair data comprise the data saved in a sum file.

Now then we would like to calculate a new "sum" file from the data pairs, excluding the contaminated pairs. But the problem is that we don't know which one (or more) of these pairs may have been corrupted. The source of the corruption may be electrical or fauna in the beam, but the end result is a corrupt signal. The result of including a corrupt signal is to increase the size of the standard deviations in the resulting calculation.

The simple solution to this problem is to calculate a sum file for every combination of the pairs, and select the set of pairs that minimizes the errors. Thus, we have to evaluate  $\sim 2^{N_{\text{PAIRS}}}$  number of sum files. Actually there are not quite this many since we have to have more than one pair to calculate statistics, so really we have  $2^{N_{\text{PAIRS}}} - N_{\text{PAIRS}}$ .

We are going to implement this using a vector mask to select which pair to use. So if we have three pairs, we set up a mask as [1,1,1] to use all three. To deselect a pair, say pair 2, we would use a mask like [1,0,1]. To generate these mask vectors, we can use bit operators on an integer number. For our three pair example we have:

0 = [ 0,0,0]	-> no pairs; don't use
1 = [ 0,0,1]	-> one pair; don't use
2 = [ 0,1,0]	-> one pair; don't use
3 = [ 0,1,1]	-> pairs 2,3
4 = [ 1,0,0]	-> one pair; don't use
5 = [ 1,0,1]	-> pairs 1,3
6 = [ 1,1,0]	-> pairs 1,2
7 = [ 1,1,1]	-> pairs 1,2,3

So we are only calculating for 3, 5, 6, 7, or 4 pairs total, not quite as onerous as it first looked!

We now have a large set of statistics calculated, so what are we going to do with it? Recall that the objective here is to find a set of pairs that reduces the error over the whole spectral range. Another way to say this is to remove pairs to find the set that has the smallest error.

The a priori information we are working from is that all the pairs are generated while viewing the same source and that the instrument is stable over the time of the measurement. We can make no

assumptions about the spectral signatures of either the source or the contamination. The only assumption is that the contamination is present in a limited subset of the available number of scans.

So using the standard deviation as a measure of the error, we need to figure out which pairs to exclude. Since the BASS data are spectral, we chose to average the standard deviation over wavelength to make the decision based on a scalar quantity. We could pick a single wavelength or a range of wavelengths, but with no prior information, the average is a good place to start. We do know that the real-time output is generated from a subset of the available wavelength channels, and we will leave the option of looking at a user-defined subset in the procedure. Further, we would like to maximize the number of pairs kept in the average, so as to increase the statistical fidelity of the answer. The process then is to average the standard deviation over the desired spectral interval for all possible pair combinations, reduce the combination space based on a user-input criterion of number of pairs to discard (e.g., discard 1 pair only), compare against the "all-pairs" case, and chose the combination with the lowest value.

The BASS data consists of three signals: the AC weighted, DC weighted, and DC signals. These are each handled independently in the calculation procedure, and the optimal selection of pairs is made for each signal. The final decision on pairs is made as a majority vote between the three signals, with equal weighting given to each signal.

### 3. Calculations

Data from observations of Comet NEAT (C/2001 Q4) taken 21 June 2004 from MLOF were used for testing. This particular observation was known to have a single bad pair based on the real-time signals monitored during the observations. The data consisted of 10 pairs, resulting in a total of 1013 possible combinations to be tested. The algorithm was allowed to test for discarding a maximum of 5 pairs.

The resulting 638 combinations for the AC-weighted error term are shown in Figure 1. here the y-axis shows the percentage difference in error as compared to using all 10 pairs in the calculation. The best pair combination here was pair index 546, which excluded pairs 5 and 6, as shown in the algorithm output of Table 1. The voting process between the three signals resulted in pair 6 being excluded.

Figure 2 shows the resulting filtered data in the thermal infrared region of the spectrum. The change in error bars is subtle in comparison, as would be expected for the small improvement obtained. Since the improvement decision is based on the wavelength-averaged error, an improvement in a noisy region of the spectrum will have significant impact on the final decision.

Table 1. Pair Voting for the Three BASS Signals. From these votes, pair 6 was selected to be discarded. (1 indicates a vote to keep; 0 indicates to discard.)

Pair Index	AC Weighted	DC Weighted	DC Signal
0	1	1	0
1	1	1	1
2	1	1	1
3	1	1	1
4	1	1	1
5	0	1	1
6	0	1	0
7	1	1	0
8	1	1	0
9	1	1	0



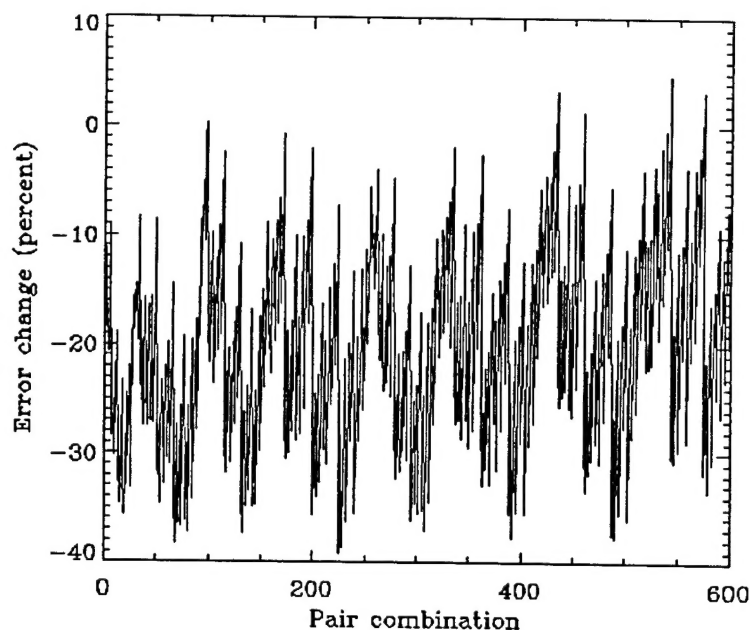


Figure 1. Improvement in mean error for the AC-weighted signal for various combinations of pairs. Here, the maximum improvement is obtained for pair index 546, which excludes pair 6 from the calculations.

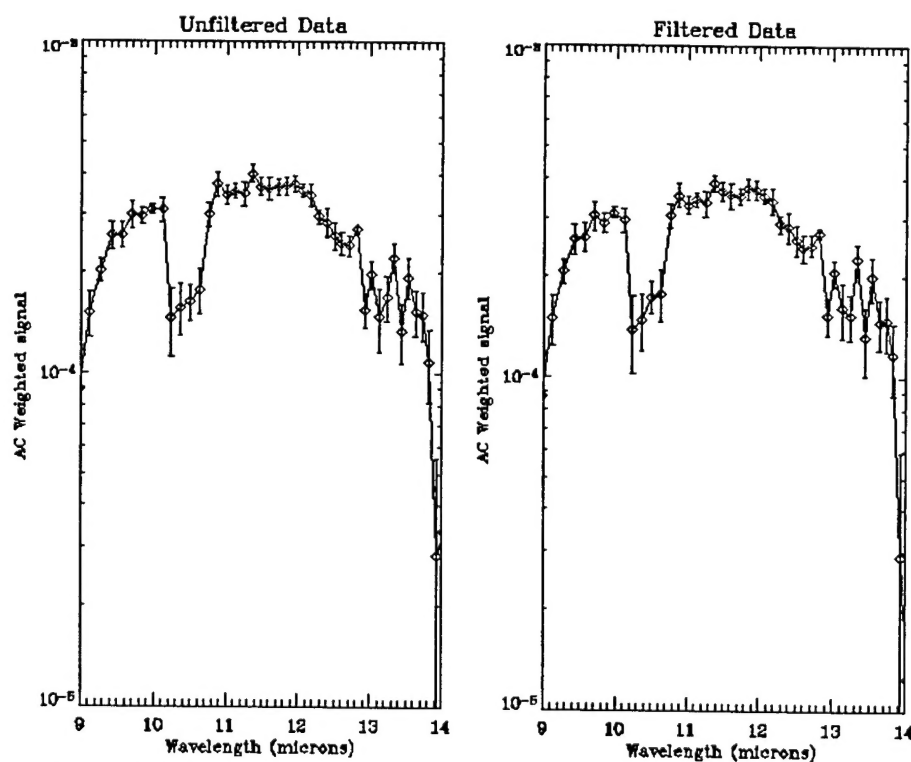


Figure 2. Comparison of filtered versus unfiltered AC-weighted data with error bars for the thermal infrared observations of Comet Neat (C/2001 Q4). These data were taken 21 June 2004 with BASS from MLOF.

#### **4. Summary and Conclusions**

A procedure has been developed to filter BASS pair data to mitigate the impact of pairs contaminated by aircraft or fauna. The procedure involves searching the entire combination space of all possible pairs. While this requires a significant number of calculations, the procedure runs with acceptable performance on a late-model desktop computer. This tool provides a new capability for the analysis of BASS data to improve the confidence in the results. Future work along these lines is anticipated in the development of alternative metrics for deciding which pairs to discard.

## LABORATORY OPERATIONS

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